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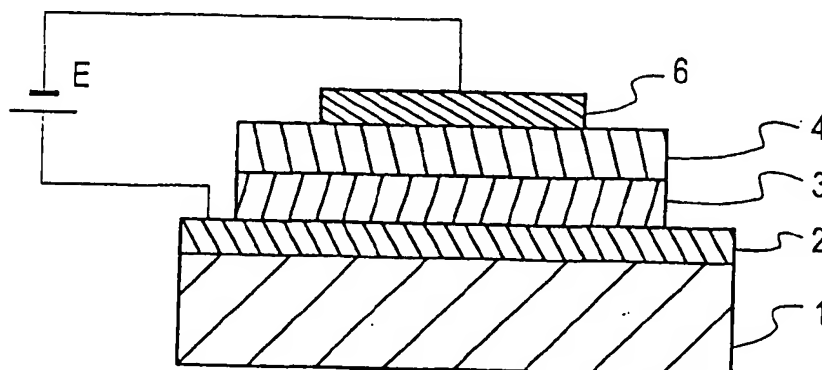
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(54) Organic electroluminescent device

(57) An organic EL device has a hole injecting electrode, an electron injecting electrode, at least one organic layer between the electrodes, and an inorganic insulating hole injecting and transporting layer between the hole injecting electrode and the organic layer. The inorganic insulating hole injecting and transporting layer contains silicon oxide and/or germanium oxide as a main component, the main component being represent-

ed by  $(\text{Si}_{1-x}\text{Ge}_x)\text{O}_y$ , wherein  $0 \leq x \leq 1$  and  $1.8 \leq y \leq 2.5$ , and further contains 0.01 to 2% by weight of at least one element selected from among Ar, Kr, Xe, and Ne. The device has the advantages of both organic and inorganic materials, a long lifetime, improved efficiency, low operating voltage, and low cost, and can provide a high luminance of light emission when applied to displays of the time-division driving mode, and realize large screen, high definition displays.

FIG. 1



## Description

### BACKGROUND OF THE INVENTION

#### Technical Field

[0001] This invention relates to an organic electroluminescent (EL) device and more particularly, to an inorganic/organic junction structure suitable for use in a device of the type wherein an electric field is applied to a thin film of an organic compound to emit light.

#### Background Art

[0002] In general, organic EL devices have a basic configuration including a glass substrate, a transparent electrode of ITO etc., a hole transporting layer of an organic amine compound, a light emitting layer of an organic material exhibiting electronic conductivity and intense light emission such as Alq<sub>3</sub>, and an electrode of a metal having a low work function such as MgAg, wherein the layers are stacked on the substrate.

[0003] The device configurations which have been reported thus far have one or more organic compound layers interposed between a hole injecting electrode and an electron injecting electrode. Structures having two or three organic compound layers are typical.

[0004] Included in the two-layer structure are a structure having a hole transporting layer and a light emitting layer formed between the hole injecting electrode and the electron injecting electrode and another structure having a light emitting layer and an electron transporting layer formed between the hole injecting electrode and the electron injecting electrode. Included in the three-layer structure is a structure having a hole transporting layer, a light emitting layer, and an electron transporting layer formed between the hole injecting electrode and the electron injecting electrode. Also known is a one-layer structure wherein a single layer playing all the roles is formed from a polymer or a mixed system.

[0005] FIGS. 3 and 4 illustrate typical configurations of organic EL devices.

[0006] In FIG. 3, a hole transporting layer 14 and a light emitting layer 15, both of organic compounds, are formed between a hole injecting electrode 12 and an electron injecting electrode 13 on a substrate 11. In this configuration, the light emitting layer 15 also serves as an electron transporting layer.

[0007] In FIG. 4, a hole transporting layer 14, a light emitting layer 15, and an electron transporting layer 16, all of organic compounds, are formed between a hole injecting electrode 12 and an electron injecting electrode 13 on a substrate 11.

[0008] Reliability is a common problem to be solved for these organic EL devices. More particularly, organic EL devices in principle have a hole injecting electrode and an electron injecting electrode and need organic layers for effectively injecting and transporting holes and

electrons from the electrodes, respectively. However, the organic materials of which the organic layers are formed are vulnerable during manufacture and have less affinity to the electrodes. Another problem is raised by the significantly accelerated degradation of organic thin films as compared with LED and LD.

[0009] Also, most organic materials are relatively expensive. Any partial replacement of constituent films by an inexpensive inorganic material would give an economical merit in the manufacture of cost effective organic EL device-applied products.

[0010] There is also a desire to have an organic EL device having a further improved light emission efficiency, a low drive voltage and a minimal current consumption.

[0011] To solve this and other problems, a means for taking advantage of both an organic material and an inorganic semiconductor material has been devised. That is, an organic/inorganic semiconductor junction is established by substituting an inorganic p-type semiconductor for the organic hole transporting layer. These efforts are found in Japanese Patent No. 2636341, JP-A 139893/1990, 207488/1990, and 119973/1994. However, it was impossible to design EL devices or cells which are superior in light emission properties and reliability to prior art organic EL devices.

[0012] In particular, display apparatus in which a plurality of organic EL devices are arranged in a matrix often adopt the time-division drive mode. However, upon driving in the time-division drive mode, the luminance of light emission per pixel becomes relatively lower with the increasing number of time-division. Therefore, when displays having a number of pixels and a relatively large area or high-definition displays are driven in the time-division mode, it becomes difficult to maintain a luminance necessary as a display screen or to carry out multi-gradation control, failing to provide displays of high image quality.

### SUMMARY OF THE INVENTION

[0013] An object of the present invention is to provide an organic EL device which can take advantage of both an organic material and an inorganic material, and has an extended effective life, an improved efficiency, a low drive voltage and a low cost.

[0014] Another object of the present invention is to provide an organic EL device which can provide a high luminance of light emission when applied to displays of the time-division drive mode and realize a large screen, high definition display.

[0015] Japanese Patent No. 2793383 discloses an organic EL device comprising an insulating metal oxide layer having an energy gap of at least 4.0 eV between a light emitting layer and a cathode. However, this insulating layer is formed between the negative electrode and the light emitting layer and thus differs from the hole injecting and transporting layer which is formed between

the hole injecting electrode and the light emitting layer. Also, the materials examined in Examples are only MgO and BaO. In the prior art section of this patent, it is described to form an SiO<sub>2</sub> layer on the ITO electrode as the insulating layer. However, it is pointed out in the patent that when the SiO<sub>2</sub> layer is formed by sputtering or similar methods, there occur the malign influences that the organic substance can be melted and crystallized so that its function is deteriorated, and sputtering particles attack the organic substance and alter the interface so that its electron or hole injecting property is lost.

[0016] JP-A 37883/1986 which is cited as the prior art reference in the above-referred patent describes an electroluminescent device comprising two electrode layers at least one of which is transparent, two light emitting layers formed between the two electrode layers, and a transparent or translucent electrode formed between the two light emitting layers wherein either one of the two light emitting layers is a monomolecular film of an organic compound or a layer of stacked monomolecular films. Also described therein as a third layer is an insulating layer having the functions of enhancing the insulation of capacitor structure and confining electron transfer within the necessary minimum area to achieve light emission by efficient exchange of electrons. The thickness of this layer is up to 500 angstroms, preferably up to 200 angstroms. It is described in the Example of forming the light emitting layer No.17 that an SiO<sub>2</sub> layer of 1,000 angstroms thick is formed on ITO as the insulating layer. However, the electroluminescent device described in this reference is designed for ac driving. Consequently, no reference is made to the function of the insulating layer as a hole injecting layer for positively injecting holes in the dc or pulse drive mode.

[0017] JP-A 288069/1996 describes an organic electroluminescent device comprising an organic layer containing at least a light emitting layer formed between a hole injecting electrode and an electron injecting electrode, wherein an insulating thin film layer is formed between either one of the above-described electrodes and the organic layer. Preferably, a nitride, more preferably aluminum nitride or tantalum nitride is used as the material of which the insulating thin film layer is made. As the material of the insulating thin film layer, GeO, GeO<sub>2</sub>, SiO, and SiO<sub>2</sub> are described. The thickness of this insulating thin film is referred to only in Examples where the thickness is always 50 angstroms. However, it is clearly seen from the above description that the preferred materials of the insulating thin film are nitrides, but not silicon oxide and germanium oxide. This insulating thin film layer plays the role of a buffer layer, while no reference is made to its hole injection and electron blocking functions.

[0018] Also, none of these patents describe that the sputtering gas such as argon, krypton, or xenon is introduced into the film being formed, and the content of sputtering gas is described nowhere.

[0019] The above objects are achieved by the present

invention that is defined below.

- (1) An organic electroluminescent device comprising a hole injecting electrode, an electron injecting electrode, at least one organic layer between the electrodes, and an inorganic insulating hole injecting and transporting layer between said hole injecting electrode and said organic layer, wherein said inorganic insulating hole injecting and transporting layer contains silicon oxide and/or germanium oxide as a main component, the main component being represented by the formula:



wherein  $0 \leq x \leq 1$  and  $1.8 \leq y \leq 2.5$ , and further contains 0.01 to 2% by weight of at least one element selected from the group consisting of argon, krypton, xenon, and neon.

- (2) The organic electroluminescent device of (1) wherein said inorganic insulating hole injecting and transporting layer has a thickness of 0.1 to 3 nm.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. 1 is a schematic cross-sectional view illustrating the configuration of an organic EL device according to one embodiment of the invention.

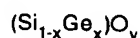
[0021] FIG. 2 is a schematic cross-sectional view illustrating the configuration of an organic EL device according to another embodiment of the invention.

[0022] FIG. 3 is a schematic cross-sectional view illustrating an organic EL device of the two-layer structure having a hole transporting layer.

[0023] FIG. 4 is a schematic cross-sectional view illustrating an organic EL device of the three-layer structure having a hole transporting layer and an electron transporting layer.

## BEST MODE FOR CARRYING OUT THE INVENTION

[0024] The organic EL device of the invention has a hole injecting electrode and an electron injecting electrode on a substrate, and an organic layer participating in at least light emission between the electrodes. An inorganic insulating hole injecting and transporting layer is disposed between the hole injecting electrode and the organic layer. The hole injecting layer contains silicon oxide and/or germanium oxide, the oxide being represented by the formula:



wherein  $0 \leq x \leq 1$  and  $1.8 \leq y \leq 2.5$ , and further contains 0.01 to 2% by weight of at least one element selected from among Ar, Kr, Xe, and Ne.

[0025] Controlling the oxide as the main component of the inorganic insulating hole injecting and transporting layer so as to fall within the above-defined composition range allows effective injection of holes from the hole injecting electrode to the organic layer on the light emitting layer side and additionally, restrains migration of electrons from the organic layer to the hole injecting electrode, ensuring effective recombination of holes and electrons in the light emitting layer. Since hole injection and transportation is intended, no light emission occurs with a reverse bias voltage applied. The organic EL device of the invention is effectively applicable to displays of the time-division drive mode in which a high luminance of light emission is required and has both the advantages of inorganic material and the advantages of organic material. The organic EL device of the invention produces a luminance comparable to those of prior art devices having an organic hole injecting layer. Owing to high heat resistance and weather resistance, the organic EL device of the invention has a longer service life than the prior art devices and develops minimal leaks and dark spots. The use of an inexpensive, readily available inorganic material rather than relatively expensive organic materials offers the advantages of easy manufacture and a reduced manufacture cost.

[0026] It suffices that  $y$  representative of the oxygen content falls within the above-defined composition range, that is,  $y$  is at least 1.8 and up to 2.5. If  $y$  is outside this range, the layer has a reduced hole injecting capability, leading to a drop of luminance. Preferably  $y$  is up to 2.4, more preferably up to 2.3, and especially up to 2.4. At the same time,  $y$  is preferably at least 2.01, more preferably at least 2.02, and especially at least 2.05.

[0027] The inorganic insulating hole injecting and transporting layer may be a thin film of silicon oxide or germanium oxide or a mixture of silicon oxide and germanium oxide. Symbol  $x$  representative of the germanium to silicon ratio is  $0 \leq x \leq 1$ . Preferably  $x$  is up to 0.4, more preferably up to 0.3, especially up to 0.2.

[0028] Alternatively,  $x$  is preferably at least 0.6, more preferably at least 0.7, especially at least 0.8.

[0029] Whether the value of  $x$  is more than or less than 0.5 may be determined in accordance with the construction of the device, the compatibility with the organic layer, and other factors, so as to provide the optimum composition.

[0030] As long as the overall hole injecting layer has the above-described composition on the average, the hole injecting layer need not be uniform in composition and may be of a structure having a graded concentration in a thickness direction.

[0031] The inorganic insulating hole injecting and transporting layer further contains 0.01 to 2% by weight, preferably 0.05 to 1.5% by weight of at least one element selected from among argon, krypton, xenon, and neon. These elements may be contained alone or in admixture of two or more. The mixture of two or more elements may have an arbitrary mix ratio.

[0032] These elements are used as the sputtering gas and thus introduced into the inorganic insulating hole injecting and transporting layer during its formation. If the content of these elements is too high, the trapping capability becomes extremely low and the desired performance is lost.

[0033] The content of the sputtering gas is determined by the pressure, the flow rate ratio of sputtering gas to oxygen, deposition rate, and other factors during film formation, especially the pressure during film formation. In order that the content of the sputtering gas fall within the above-described range, it is preferred to effect film deposition in higher vacuum, specifically in a vacuum of 1 Pa or lower, especially 0.1 to 1 Pa.

[0034] The inorganic insulating hole injecting and transporting layer is normally amorphous.

[0035] The thickness of the inorganic insulating hole injecting and transporting layer is preferably about 0.1 nm to about 3 nm, more preferably about 0.3 nm to about 0.9 nm. Hole injection would become insufficient when the thickness of the inorganic insulating hole injecting and transporting layer is outside the range.

[0036] Methods for preparing the inorganic insulating hole injecting and transporting layer include various physical and chemical thin film forming methods such as sputtering and electron beam (EB) vapor deposition, with the sputtering being preferred.

[0037] When the inorganic insulating hole injecting and transporting layer is formed by sputtering, the sputtering gas is preferably under a pressure of 0.1 to 1 Pa during sputtering. The sputtering gas may be any of inert gases used in conventional sputtering equipment, for example, Ar, Ne, Xe, and Kr. Nitrogen ( $N_2$ ) gas and hydrogen ( $H_2$ ) gas may be used if necessary. Reactive sputtering may be carried out in an atmosphere of the sputtering gas mixed with about 1 to about 99% of oxygen ( $O_2$ ) gas. The target used herein is the above-described oxide or oxides, and either single source or multiple source sputtering may be carried out.

[0038] The sputtering process may be an RF sputtering process using an RF power source or a DC reactive sputtering process, with the former being especially preferred. The power of the sputtering equipment is preferably in the range of 0.1 to 10 W/cm<sup>2</sup> for RF sputtering. The deposition rate is in the range of 0.1 to 50 nm/min., preferably 0.5 to 10 nm/min., more preferably 1 to 10 nm/min., and especially 1 to 5 nm/min. The temperature of the substrate during deposition is from room temperature (25°C) to about 150°C.

[0039] The organic EL device of the invention may have, as shown in FIG. 1, the successively stacked configuration of substrate 1/hole injecting electrode 2/inorganic insulating hole injecting and transporting layer 3/light emitting layer 4/electron injecting electrode 5. Another possible configuration is, as shown in FIG. 2, the configuration of substrate 1/hole injecting electrode 2/inorganic insulating hole injecting and transporting layer 3/light emitting layer 4/electron injecting layer 5/electron

injecting electrode (negative electrode) 6. Moreover, reversely stacked configurations obtained by reversing the order of stacking are also acceptable. The reversely stacked configuration helps light emerge from the side of the assembly opposite to the substrate. In the reversely stacked configuration, however, when the inorganic insulating hole injecting and transporting layer is deposited, the organic layer and other layer (if any) can be subjected to ashing and hence, damaged. It is thus recommended that the hole injecting layer is initially thinly deposited in the absence of oxygen and then thickly in the presence of oxygen. The thickness reached in the absence of oxygen is preferably about 1/5 to about 1/2 of the final thickness. In FIGS. 1 and 2, a drive power supply E is connected between the hole injecting electrode 2 and the electron injecting electrode 6. It is understood that the light emitting layer 4 is a light emitting layer of broader definition including a hole transporting layer, a light emitting layer of narrower definition, an electron transporting layer, a mix layer thereof, and so on.

[0040] The device of the invention may have a multi-stage configuration of electrode layer/inorganic layer (inorganic insulating hole injecting layer) and light emitting layer/electrode layer/inorganic layer and light emitting layer/electrode layer/inorganic layer and light emitting layer/electrode layer, or further repeated layers. Such a multi-stage configuration is effective for adjusting or multiplying the color of emitted light.

[0041] For the hole injecting electrode, materials capable of effectively injecting holes into the hole injecting layer are preferred. Useful are compositions based on tin-doped indium oxide (ITO), zinc-doped indium oxide (IZO), indium oxide ( $\text{In}_2\text{O}_3$ ), tin oxide ( $\text{SnO}_2$ ) or zinc oxide ( $\text{ZnO}$ ). These oxides may deviate more or less from their stoichiometric compositions. For ITO, an appropriate proportion of  $\text{SnO}_2$  mixed with  $\text{In}_2\text{O}_3$  is about 1 to 20%, more preferably about 5 to 12% by weight. For IZO, an appropriate proportion of  $\text{ZnO}$  mixed with  $\text{In}_2\text{O}_3$  is about 12 to 32% by weight. The hole injecting electrode may further contain silicon oxide ( $\text{SiO}_2$ ). The content of silicon oxide ( $\text{SiO}_2$ ) is preferably about 0.5 to 10% as expressed in mol percent of  $\text{SiO}_2$  based on ITO.

[0042] The electrode on the light exit side should preferably have a light transmittance of at least 50%, more preferably at least 60%, further preferably at least 80%, especially at least 90% in the light emission band, typically from 400 to 700 nm, and especially at each light emission. With a lower transmittance, the light emitted by the light emitting layer is attenuated through the electrode, failing to provide a luminance necessary as a light emitting device. It is noted that the light transmittance of the electrode is sometimes intentionally set low for the purpose of increasing the contrast ratio for improving visual perception.

[0043] Preferably the electrode has a thickness of 50 to 500 nm, especially 50 to 300 nm. Although the upper limit of the electrode thickness is not critical, a too thick

electrode would cause a drop of transmittance and separation. Too thin an electrode is insufficient for its effect and low in film strength during fabrication.

[0044] The electron injecting electrode is preferably formed from materials having a low work function, for example, metal elements such as K, Li, Na, Mg, La, Ce, Ca, Sr, Ba, Al, Ag, In, Sn, Zn, and Zr, and binary or ternary alloys made of two or three such metal elements for stability improvement. Exemplary alloys are Ag-Mg (Ag: 0.1 to 50 at%), Al-Li (Li: 0.01 to 14 at%, especially 0.01 to 12 at%), In-Mg (Mg: 50 to 80 at%), and Al-Ca (Ca: 0.01 to 20 at%). A thin film of such a material or a multilayer film of two or more materials may be used as the electron injecting electrode layer.

[0045] The electron injecting electrode thin film may have at least a sufficient thickness to effect electron injection, for example, a thickness of at least 0.1 nm, preferably at least 0.2 nm, more preferably at least 0.5 nm, especially at least 1 nm. Although the upper limit is not critical, the electrode thickness is typically about 1 to about 500 nm. On the electron injecting electrode, an auxiliary or protective electrode may be provided.

[0046] The auxiliary electrode may have at least a sufficient thickness to ensure efficient electron injection and prevent the ingress of moisture, oxygen and organic solvents, for example, a thickness of at least 50 nm, preferably at least 100 nm, more preferably 100 to 500 nm. A too thin auxiliary electrode layer would exert its effect little, lose a step coverage capability, and provide insufficient connection to a terminal electrode. If too thick, greater stresses are generated in the auxiliary electrode layer, accelerating the growth rate of dark spots.

[0047] For the auxiliary electrode, an appropriate material may be chosen in consideration of the material of the electron injecting electrode to be combined therewith. For example, low resistivity metals such as aluminum may be used when electron injection efficiency is of importance. Metal compounds such as TiN may be used when sealing is of importance.

[0048] The thickness of the electron injecting electrode and the auxiliary electrode combined is usually about 50 to about 500 nm though it is not critical.

[0049] The light emitting layer is a thin film of an organic compound participating in light emission or a multilayer film of two or more organic compounds participating in light emission.

[0050] The light emitting layer has the functions of injecting holes and electrons, transporting them, and recombining holes and electrons to create excitons. It is preferred that relatively electronically neutral compounds be used in the light emitting layer so that electron and holes may be readily injected and transported in a well-balanced manner.

[0051] In addition to the light emitting layer of the narrow definition, the light emitting layer may optionally include layers of organic materials such as a hole transporting layer and an electron injecting and transporting

layer.

**[0052]** The optional hole transporting layer has the functions of facilitating injection of holes from the inorganic insulating hole injecting and transporting layer, transporting holes stably, and blocking electrons. The optional electron injecting and transporting layer has the functions of facilitating injection of electrons from the electron injecting electrode, transporting electrons stably, and blocking holes. These layers are effective for increasing the number of holes and electrons injected into the light emitting layer and confining holes and electrons therein for optimizing the recombination region to improve light emission efficiency.

**[0053]** The thicknesses of the light emitting layer, the hole transporting layer, and the electron injecting and transporting layer are not critical and vary with a particular formation technique although their thickness is usually preferred to range from about 5 nm to about 500 nm, especially from about 10 nm to about 300 nm.

**[0054]** The thickness of the hole transporting layer and the electron injecting and transporting layer is equal to or ranges from about 1/10 times to about 10 times the thickness of the light emitting layer although it depends on the design of a recombination/light emitting region. When the electron injecting and transporting layer is divided into an injecting layer and a transporting layer, preferably the injecting layer is at least 1 nm thick and the transporting layer is at least 1 nm thick. The upper limit of thickness is usually about 500 nm for the injecting layer and about 500 nm for the transporting layer. The same film thickness applies when two injecting/transporting layers are provided.

**[0055]** The light emitting layer of the organic EL device of the invention contains a fluorescent material that is a compound having a light emitting capability. The fluorescent material may be at least one member selected from compounds as disclosed, for example, in JP-A 264692/1988, such as quinacridone, rubrene, and styryl dyes. Also, quinoline derivatives such as metal complex dyes having 8-quinolinol or a derivative thereof as the ligand such as tris(8-quinolinolato)aluminum are included as well as tetraphenylbutadiene, anthracene, perylene, coronene, and 12-phthaloperinone derivatives. Further useful are the phenylanthracene derivatives described in JP-A 12600/1996 and the tetraarylethene derivatives described in JP-A 12969/1996.

**[0056]** It is preferred to use such a compound in combination with a host material capable of light emission by itself, that is, to use the compound as a dopant. In this embodiment, the content of the compound in the light emitting layer is preferably 0.01 to 10% by weight, especially 0.1 to 5% by weight. By using the compound in combination with the host material, the light emission wavelength of the host material can be altered, allowing light emission to be shifted to a longer wavelength and improving the luminous efficacy and stability of the device.

**[0057]** As the host material, quinolinolato complexes

are preferable, with aluminum complexes having 8-quinolinol or a derivative thereof as the ligand being more preferable. These aluminum complexes are disclosed in JP-A 264692/1988, 255190/1991, 70733/1993, 258859/1993 and 215874/1994.

**[0058]** Illustrative examples include tris(8-quinolinolato)aluminum, bis(8-quinolinolato)magnesium, bis(benzo[*f*]-8-quinolinolato)zinc, bis(2-methyl-8-quinolinolato)aluminum oxide, tris(8-quinolinolato)indium, tris(5-methyl-8-quinolinolato)aluminum, 8-quinolinolato-lithium, tris(5-chloro-8-quinolinolato)gallium, bis(5-chloro-8-quinolinolato)calcium, 5,7-dichloro-8-quinolinolatoaluminum, tris(5,7-dibromo-8-hydroxyquinolinolato)aluminum, and poly[zinc(II)-bis(8-hydroxy-5-quinolinyl)methane].

**[0059]** Also useful are aluminum complexes having another ligand in addition to 8-quinolinol or a derivative thereof. Examples include bis(2-methyl-8-quinolinolato)(phenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(orthocresolato)aluminum(III), bis(2-methyl-8-quinolinolato)(metacresolato)aluminum(III), bis(2-methyl-8-quinolinolato)(paracresolato)aluminum(III), bis(2-methyl-8-quinolinolato)(ortho-phenylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(meta-phenylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(para-phenylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(2,3-dimethylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(2,6-dimethylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(3,4-dimethylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(3,5-dimethylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(3,5-di-tert-butylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(2,6-diphenylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(2,4,6-triphenylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(2,3,6-trimethylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(2,3,5,6-tetramethylphenolato)aluminum(III), bis(2-methyl-8-quinolinolato)(1-naphtholato)aluminum(III), bis(2-methyl-8-quinolinolato)(2-naphtholato)aluminum(III), bis(2,4-dimethyl-8-quinolinolato)(orthophenylphenolato)aluminum(III), bis(2,4-dimethyl-8-quinolinolato)(para-phenylphenolato)aluminum(III), bis(2,4-dimethyl-8-quinolinolato)(meta-phenylphenolato)aluminum(III), bis(2,4-dimethyl-8-quinolinolato)(3,5-dimethylphenolato)aluminum(III), bis(2,4-dimethyl-8-quinolinolato)(3,5-di-tert-butylphenolato)aluminum(III), bis(2-methyl-4-ethyl-8-quinolinolato)(para-cresolato)aluminum(III), bis(2-methyl-4-methoxy-8-quinolinolato)(para-phenylphenolato)aluminum(III), bis(2-methyl-5-cyano-8-quinolinolato)(ortho-cresolato)aluminum(III), and bis(2-methyl-6-trifluoromethyl-8-quinolinolato)(2-naphtholato)aluminum(III).

**[0060]** Also acceptable are bis(2-methyl-8-quinolinolato)aluminum(III)- $\mu$ -oxo-bis(2-methyl-8-quinolinolato)aluminum(III), bis(2,4-dimethyl-8-quinolinolato)aluminum(III)- $\mu$ -oxo-bis(2,4-dimethyl-8-quinolinolato)aluminum(III), bis(4-ethyl-2-methyl-8-quinolinolato)aluminum(III)- $\mu$ -oxo-bis(4-ethyl-2-methyl-8-quinolinolato)aluminum(III).

linolato)aluminum(III), bis(2-methyl-4-methoxyquinolinolato)aluminum(III)- $\mu$ -oxo-bis(2-methyl-4-methoxyquinolinolato)aluminum(III), bis(5-cyano-2-methyl-8-quinolinolato)aluminum(III)- $\mu$ -oxo-bis(5-cyano-2-methyl-8-quinolinolato)aluminum(III), and bis(2-methyl-5-trifluoromethyl-8-quinolinolato)aluminum(III)- $\mu$ -oxo-bis(2-methyl-5-trifluoromethyl-8-quinolinolato)aluminum(III).

**[0061]** Other useful host materials are the phenylanthracene derivatives described in JP-A 12600/1996 and the tetraarylethene derivatives described in JP-A 12969/1996.

**[0062]** The light emitting layer may also serve as the electron injecting and transporting layer. In this case, tris(8-quinolinolato)aluminum etc. are preferably used. These fluorescent materials may be evaporated.

**[0063]** Also, if necessary, the light emitting layer may also be a layer of a mixture of at least one hole injecting and transporting compound and at least one electron injecting and transporting compound, in which a dopant is preferably contained. In such a mix layer, the content of the compound is preferably 0.01 to 20% by volume, especially 0.1 to 15% by volume.

**[0064]** In the mix layer, carrier hopping conduction paths are created, allowing carriers to move through a polarly predominant material while injection of carriers of opposite polarity is rather inhibited, and the organic compound becomes less susceptible to damage, resulting in the advantage of an extended device life. By incorporating the aforementioned dopant in such a mix layer, the light emission wavelength the mix layer itself possesses can be altered, allowing light emission to be shifted to a longer wavelength and improving the luminous intensity and stability of the device.

**[0065]** The hole injecting and transporting compound and electron injecting and transporting compound used in the mix layer may be selected from compounds for the hole transporting layer and compounds for the electron injecting and transporting layer to be described later, respectively. Inter alia, the compound for the hole transporting layer is preferably selected from amine derivatives having strong fluorescence, for example, triphenyldiamine derivatives which are hole transporting materials, styrylamine derivatives and amine derivatives having an aromatic fused ring.

**[0066]** The electron injecting and transporting compound is preferably selected from quinoline derivatives and metal complexes having 8-quinolinol or a derivative thereof as a ligand, especially tris(8-quinolinolato)aluminum (Alq3). The aforementioned phenylanthracene derivatives and tetraarylethene derivatives are also preferable.

**[0067]** For the hole transporting layer, amine derivatives having intense fluorescence are useful, for example, the triphenyldiamine derivatives, styrylamine derivatives, and amine derivatives having an aromatic fused ring, exemplified above as the hole transporting material.

**[0068]** The mix ratio is preferably determined in accordance with the carrier density and carrier mobility. It is usually preferred that the weight ratio of the hole injecting and transporting compound to the electron injecting and transporting compound range from about 1/99 to about 99/1, more preferably from about 10/90 to about 90/10, especially from about 20/80 to about 80/20.

**[0069]** Also preferably, the thickness of the mix layer ranges from the thickness of a mono-molecular layer to less than the thickness of the organic compound layer, specifically from 1 to 85 nm, more preferably 5 to 60 nm, especially 5 to 50 nm.

**[0070]** Preferably the mix layer is formed by a co-deposition process of evaporating the compounds from distinct sources. If both the compounds have approximately equal or very close vapor pressures or evaporation temperatures, they may be pre-mixed in a common evaporation boat, from which they are evaporated together. The mix layer is preferably a uniform mixture of both the compounds although the compounds can be present in island form. The light emitting layer is generally formed to a predetermined thickness by evaporating an organic fluorescent material or coating a dispersion thereof in a resin binder.

**[0071]** In the hole transporting layer which is optionally provided, there may be used various organic compounds as described, for example, in JP-A 295695/1988, 191694/1990, 792/1991, 234681/1993, 239455/1993, 299174/1993, 126225/1995, 126226/1995, and 100172/1996, and EP 0650955A1. Exemplary are tetraarylbenzidine compounds (triaryldiamines or triphenyldiamines: TPD), aromatic tertiary amines, hydrazone derivatives, carbazole derivatives, triazole derivatives, imidazole derivatives, oxadiazole derivatives having an amino group, and polythiophenes. Two or more of these compounds may be used, and on such combined use, they may be formed as separate layers or mixed. The organic hole transporting layer may be provided if necessary, although the omission of this layer is preferable.

**[0072]** In the electron injecting and transporting layer which is optionally provided, there may be used quinoline derivatives including organic metal complexes having 8-quinolinol or a derivative thereof as a ligand such as tris(8-quinolinolato)aluminum (Alq3), oxadiazole derivatives, perylene derivatives, pyridine derivatives, pyrimidine derivatives, quinoxaline derivatives, diphenylquinone derivatives, and nitro-substituted fluorene derivatives. The electron injecting and transporting layer can also serve as the light emitting layer. In this case, use of tris(8-quinolinolato)aluminum etc. is preferred. Like the light emitting layer, the electron injecting and transporting layer may be formed by evaporation or the like.

**[0073]** Where the electron injecting and transporting layer is formed separately as an electron injecting layer and an electron transporting layer, two or more compounds are selected in a proper combination from the



compounds commonly used in electron injecting and transporting layers. In this regard, it is preferred to stack layers in such an order that a layer of a compound having a greater electron affinity may be disposed adjacent the electron injecting electrode. The order of stacking also applies where a plurality of electron injecting and transporting layers are provided.

**[0074]** In forming the hole transporting layer, the light emitting layer, and the electron injecting and transporting layer, vacuum evaporation is preferably used because homogeneous thin films are available. By utilizing vacuum evaporation, there is obtained a homogeneous thin film which is amorphous or has a crystal grain size of less than 0.2  $\mu\text{m}$ . If the grain size is more than 0.2  $\mu\text{m}$ , uneven light emission would take place and the drive voltage of the device must be increased with a substantial drop of hole injection efficiency.

**[0075]** The conditions for vacuum evaporation are not critical although a vacuum of  $10^{-4}$  Pa or lower and a deposition rate of about 0.01 to 1 nm/sec. are preferred. It is preferred to successively form layers in vacuum because the successive formation in vacuum can avoid adsorption of impurities on the interface between the layers, thus ensuring better performance. Also, the drive voltage of a device can be reduced and the development and growth of dark spots be restrained.

**[0076]** In the embodiment wherein the respective layers are formed by vacuum evaporation, where it is desired for a single layer to contain two or more compounds, preferably boats having the compounds received therein are individually temperature controlled to achieve co-deposition.

**[0077]** Further preferably, a shield plate may be provided on the device in order to prevent the organic layers and electrodes from oxidation. In order to prevent the ingress of moisture, the shield plate is attached to the substrate through an adhesive resin layer for sealing. The sealing gas is preferably an inert gas such as argon, helium, and nitrogen. The inert gas should preferably have a moisture content of less than 100 ppm, more preferably less than 10 ppm, especially less than 1 ppm. The lower limit of the moisture content is usually about 0.1 ppm though not critical.

**[0078]** The shield plate is selected from plates of transparent or translucent materials such as glass, quartz and resins, with glass being especially preferred. Alkali glass is preferred because of economy although other glass compositions such as soda lime glass, lead alkali glass, borosilicate glass, aluminosilicate glass, and silica glass are also useful. Of these, plates of soda glass without surface treatment are inexpensive and useful. Metal plates and plastic plates may also be used as the shield plate.

**[0079]** Using a spacer for height adjustment, the shield plate may be held at a desired height over the layer structure. The spacer may be formed from resin beads, silica beads, glass beads, and glass fibers, with the glass beads being especially preferred. Usually the

spacer is formed from particles having a narrow particle size distribution while the shape of particles is not critical. Particles of any shape which does not obstruct the spacer function may be used. Preferred particles have an equivalent circle diameter of 1 to 20  $\mu\text{m}$ , more preferably 1 to 10  $\mu\text{m}$ , most preferably 2 to 8  $\mu\text{m}$ . Particles of such diameter should preferably have a length of less than about 100  $\mu\text{m}$ . The lower limit of length is not critical although it is usually equal to or more than the diameter.

**[0080]** When a shield plate having a recess is used, the spacer may be used or not. When used, the spacer should preferably have a diameter in the above-described range, especially 2 to 8  $\mu\text{m}$ .

**[0081]** The spacer may be premixed in a sealing adhesive or mixed with a sealing adhesive at the time of bonding. The content of the spacer in the sealing adhesive is preferably 0.01 to 30% by weight, more preferably 0.1 to 5% by weight.

**[0082]** Any of adhesives which can maintain stable bond strength and gas tightness may be used although UV curable epoxy resin adhesives of cation curing type are preferred.

**[0083]** In the organic EL structure of the invention, the substrate may be selected from amorphous substrates of glass and quartz and crystalline substrates of Si, GaAs, ZnSe, ZnS, GaP, and InP, for example. If desired, buffer layers of crystalline materials, amorphous materials or metals may be formed on such crystalline substrates. Metal substrates including Mo, Al, Pt, Ir, Au and Pd are also useful. Of these, glass substrates are preferably used. Since the substrate is often situated on the light exit side, the substrate should preferably have a light transmittance as described above for the electrode.

**[0084]** A plurality of inventive devices may be arrayed on a plane. A color display is obtained when the respective devices of a planar array differ in emission color.

**[0085]** The substrate may be provided with a color filter film, a fluorescent material-containing color conversion film or a dielectric reflecting film for controlling the color of light emission.

**[0086]** The color filter film used herein may be a color filter as used in liquid crystal displays and the like. The properties of a color filter may be adjusted in accordance with the light emission of the organic EL device so as to optimize the extraction efficiency and color purity.

**[0087]** It is also preferred to use a color filter capable of cutting external light of short wavelength which is otherwise absorbed by the EL device materials and fluorescence conversion layer, because the light resistance and display contrast of the device are improved.

**[0088]** An optical thin film such as a multilayer dielectric film may be used instead of the color filter.

**[0089]** The fluorescence conversion filter film is to convert the color of light emission by absorbing electroluminescence and allowing the fluorescent material in the film to emit light. It is formed from three components: a binder, a fluorescent material, and a light absorbing material.



[0090] The fluorescent material used may basically have a high fluorescent quantum yield and desirably exhibits strong absorption in the electroluminescent wavelength region. In practice, laser dyes are appropriate. Use may be made of rhodamine compounds, perylene compounds, cyanine compounds, phthalocyanine compounds (including sub-phthalocyanines), naphthalimide compounds, fused ring hydrocarbon compounds, fused heterocyclic compounds, styryl compounds, and coumarin compounds.

[0091] The binder is selected from materials which do not cause extinction of fluorescence, preferably those materials which can be finely patterned by photolithography or printing technique. Also, where the filter film is formed on the substrate so as to be contiguous to the hole injecting electrode, those materials which are not damaged during deposition of the hole injecting electrode (such as ITO or IZO) are preferable.

[0092] The light absorbing material is used when the light absorption of the fluorescent material is short, and may be omitted if unnecessary. The light absorbing material may also be selected from materials which do not cause extinction of fluorescence of the fluorescent material.

[0093] The organic EL device of the invention is generally of the dc or pulse drive type. The applied voltage is generally about 2 to 30 volts.

#### EXAMPLE

[0094] Examples of the invention are given below by way of illustration.

##### Example 1

[0095] A substrate of (7059) glass by Corning Glass Works was scrubbed using a neutral detergent.

[0096] By RF magnetron sputtering from a target of ITO oxide, a hole injecting electrode layer of ITO having a thickness of 200 nm was formed on the substrate at a temperature of 250°C.

[0097] After its ITO electrode-bearing surface was cleaned with UV/O<sub>3</sub>, the substrate was secured by a holder in a sputtering chamber, which was evacuated to a vacuum of 1x10<sup>-4</sup> Pa or lower.

[0098] Using a target of SiO<sub>2</sub>, an inorganic insulating hole injecting and transporting layer was deposited to a thickness of 0.9 nm. The sputtering gas used was 100 sccm of Ar and 1 sccm of O<sub>2</sub>. Sputtering conditions included a substrate temperature of 25°C, a deposition rate of 1 nm/min., an operating pressure of 0.3 Pa, and an input power of 5 W/cm<sup>2</sup>. The hole injecting layer as deposited had a composition of SiO<sub>2.01</sub> containing 0.2% by weight of Ar.

[0099] With the vacuum kept, N,N,N',N'-tetrakis(m-biphenyl)-1,1'-biphenyl-4,4'-diamine (TPD), tris(8-quinololato)aluminum (Alq3), and rubrene were evaporated at an overall deposition rate of 0.2 nm/sec. to a thickness

of 100 nm, forming a light emitting layer. The layer consisted of a mixture of TPD and Alq3 in a weight ratio of 1:1 doped with 10 vol% of rubrene.

[0100] Furthermore, with the vacuum kept, tris(8-quinololato)aluminum (Alq3) was evaporated at a deposition rate of 0.2 nm/sec. to a thickness of 30 nm, forming an electron injecting and transporting layer.

[0101] With the vacuum kept, AlLi (Li 7 at%) was evaporated to a thickness of 1 nm, and Al was successively evaporated to a thickness of 200 nm to form an electron injecting electrode and an auxiliary electrode, respectively. Finally, a glass shield was sealed to the layer structure to complete an organic EL device.

[0102] An electric field was applied across the organic EL device in air, which exhibited diode characteristics. When biased to be positive on the ITO side and negative on the AlLi side, the current flow increased as the voltage increased. A distinct light emission was observed in an ordinary room. When the device was repeatedly operated for light emission, no drop of luminance occurred.

[0103] Next, by an accelerated test of driving the device at room temperature (25°C) and a constant current of 100 mA/cm<sup>2</sup>, the device was examined for luminance of light emission and life. This organic EL device had an initial luminance of 5000 cd/m<sup>2</sup>. On time-division driving, the device produced light emission with a sufficient luminance, indicating the possibility of multi-gradation (or variable contrast) driving. This organic EL device maintained more than 80% of the initial luminance even after 300 hours of continuous operation. In the organic EL device of the present invention, neither leakage nor dark spots were found.

##### Example 2

[0104] Organic EL devices were prepared as in Example 1 except that in the step of depositing the inorganic insulating hole injecting and transporting layer, the flow rate of O<sub>2</sub> in the sputtering gas and the pressure were changed. The resulting layers had the compositions SiO<sub>2.08</sub>, SiO<sub>2.1</sub>, and SiO<sub>2.2</sub>. When the devices were examined for luminance of light emission and life, there were obtained approximately equivalent results to Example 1. The contents of Ar in these samples were in the range of 0.05 to 1.5% by weight.

[0105] Also when the composition of the inorganic insulating hole injecting and transporting layer in Example 1 was changed from SiO<sub>2.08</sub> to GeO<sub>2.08</sub> with 1.0% by weight of Ar or Si<sub>0.5</sub>Ge<sub>0.5</sub>O<sub>2.08</sub> with 1.2% by weight of Ar, the results were equivalent to those of Example 1. Also, when the composition of the inorganic insulating hole injecting and transporting layer was changed from SiO<sub>2.08</sub> to GeO<sub>2.1</sub> with 0.8% by weight of Ar or Si<sub>0.5</sub>Ge<sub>0.5</sub>O<sub>2.1</sub> with 0.8% by weight of Ar, the results were equivalent to those of Example 1. When the sputtering gas was changed from argon to krypton or xenon, similar results were obtained.

### Example 3

[0106] An organic EL device was prepared as in Example 1 except that in the step of depositing the inorganic insulating hole injecting and transporting layer, the flow rates of the sputtering gases were changed to 40 sccm of Ar and 60 sccm of O<sub>2</sub>, and the pressure was 0.4 Pa. The resulting layer had the composition SiO<sub>1.9</sub> containing 0.08% by weight of Ar. The device was examined for luminance of light emission and life. When driven at a constant current of 100 mA/cm<sup>2</sup>, this device showed an initial luminance of 4800 cd/m<sup>2</sup> and the life performance was approximately equal to Example 1.

### Comparative Example 1

[0107] An organic EL device was prepared as in Example 1 except that instead of the inorganic insulating hole injecting and transporting layer, a hole injecting layer was formed by evaporating polythiophene at a deposition rate of 0.1 nm/sec. to a thickness of 10 nm, and a hole transporting layer was formed by evaporating TPD at a deposition rate of 0.1 nm/sec. to a thickness of 20 nm. The device was examined for luminance of light emission and life.

[0108] This organic EL device deteriorated to less than 60% of the initial luminance within 300 hours of operation. Current leakage and dark spots were observed.

### Comparative Example 2

[0109] An organic EL device was prepared as in Example 1 except that the composition of the inorganic insulating hole injecting and transporting layer was changed to SiO<sub>1.6</sub>. The device was examined for luminance of light emission and life.

[0110] When driven at a constant current density of 100 mA/cm<sup>2</sup>, this organic EL device showed an initial luminance of 1500 cd/m<sup>2</sup> and a luminance half-life of less than 200 hours.

### Comparative Example 3

[0111] An organic EL device was prepared as in Example 1 except that the composition of the inorganic insulating hole injecting and transporting layer was changed to SiO<sub>2.6</sub>. The device was examined for luminance of light emission and life.

[0112] This organic EL device showed an initial luminance of just 500 cd/m<sup>2</sup>, which was below the practical level.

### Comparative Example 4

[0113] A hole injecting electrode layer of ITO was formed on the substrate as in Example 1.

[0114] After its ITO electrode-bearing surface was cleaned with UV/O<sub>3</sub>, the substrate was secured by a

holder in a vacuum deposition chamber, which was evacuated to a vacuum of 1x10<sup>-4</sup> Pa or lower.

[0115] With the vacuum kept, N,N,N',N'-tetrakis(m-biphenyl)-1,1'-biphenyl-4,4'-diamine (TPD), tris(8-quinololato)aluminum (Alq3), and rubrene were evaporated at an overall deposition rate of 0.2 nm/sec. to a thickness of 100 nm, forming a light emitting layer. The layer consisted of a mixture of TPD and Alq3 in a weight ratio of 1:1 doped with 10 vol% of rubrene.

[0116] With the vacuum kept, AlLi (Li 7 at%) was evaporated to a thickness of 1 nm, and Al was successively evaporated to a thickness of 200 nm to form an electron injecting electrode and an auxiliary electrode, respectively. Finally, a glass shield was sealed to the layer structure to complete an organic EL device having only the light emitting layer.

[0117] When this organic EL device was examined as in Example 1, it showed an initial luminance of 3000 cd/m<sup>2</sup> at a constant current of 100 mA/cm<sup>2</sup>, but a luminance half-life of less than 5 minutes.

### BENEFITS OF THE INVENTION

[0118] As seen from the foregoing description, the invention provides an organic EL device which can take advantage of both organic and inorganic materials, and has an extended effective life, an improved efficiency, a low operating voltage and a low cost.

[0119] Also, the organic EL device of the invention can provide a high luminance of light emission especially when applied to displays of the time-division drive mode and thus can realize large screen, high definition displays.

### Claims

1. An organic electroluminescent device comprising a hole injecting electrode, an electron injecting electrode, at least one organic layer between the electrodes, and an inorganic insulating hole injecting and transporting layer between said hole injecting electrode and said organic layer, wherein

said inorganic insulating hole injecting and transporting layer contains silicon oxide and/or germanium oxide as a main component, the main component being represented by the formula:



wherein  $0 \leq x \leq 1$  and  $1.8 \leq y \leq 2.5$ , and further contains 0.01 to 2% by weight of at least one element selected from the group consisting of argon, krypton, xenon, and neon.

2. The organic electroluminescent device of claim 1 wherein said inorganic insulating hole injecting and

transporting layer has a thickness of 0.1 to 3 nm.

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FIG. 1

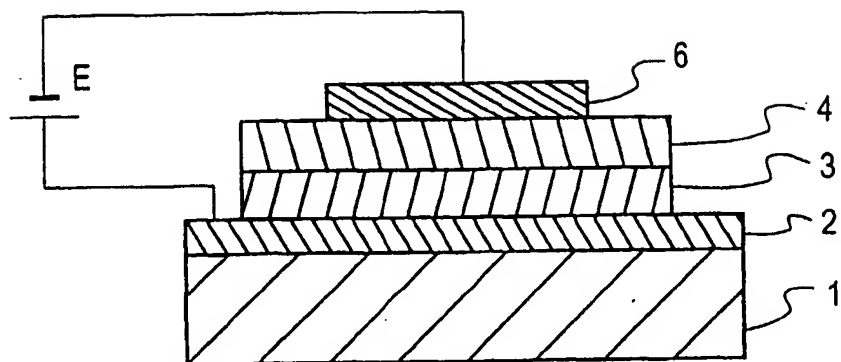


FIG. 2

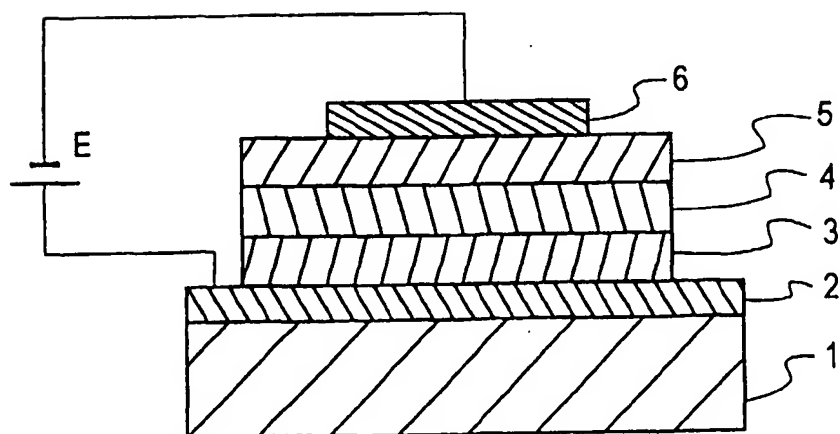


FIG. 3

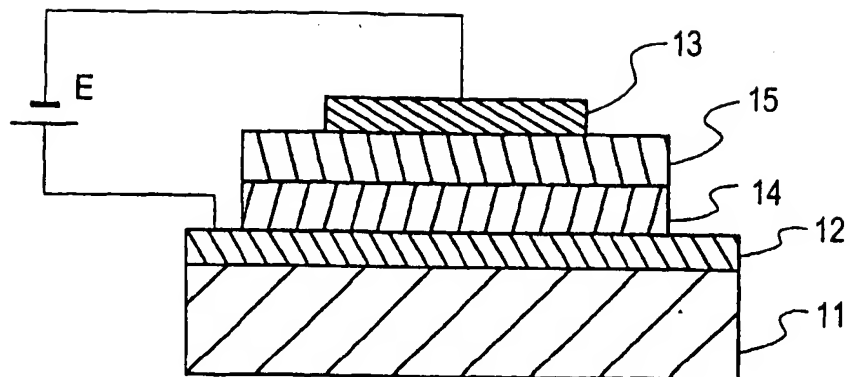
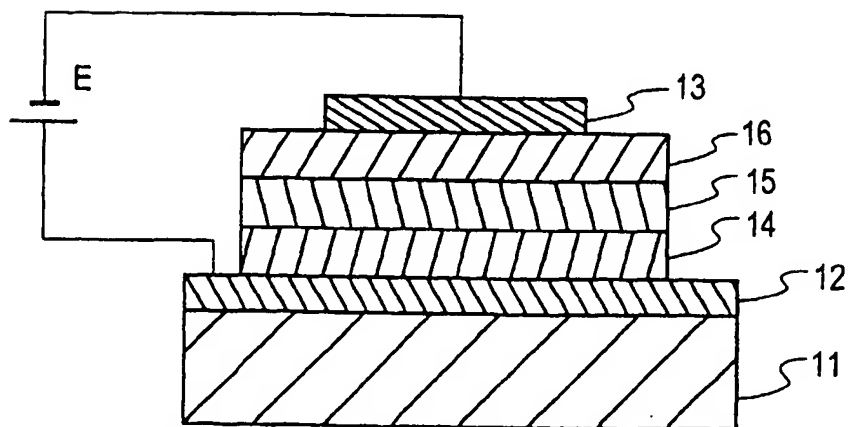


FIG. 4







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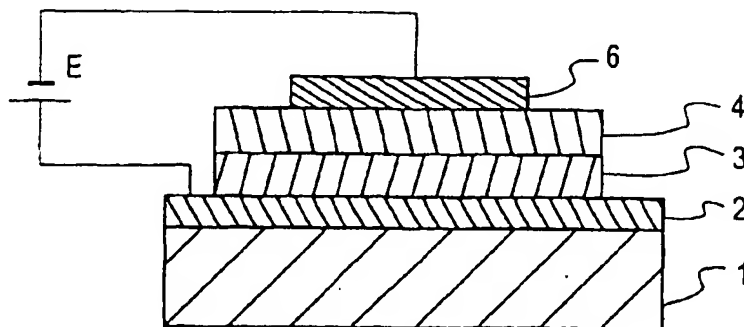
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(54) **Organic electroluminescent device**

(57) An organic EL device has a hole injecting electrode, an electron injecting electrode, at least one organic layer between the electrodes, and an inorganic insulating hole injecting and transporting layer between the hole injecting electrode and the organic layer. The inorganic insulating hole injecting and transporting layer contains silicon oxide and/or germanium oxide as a main component, the main component being represented by  $(\text{Si}_{1-x}\text{Ge}_x)\text{O}_y$  wherein  $0 \leq x \leq 1$  and  $1.8 \leq y \leq 2.5$ , and further contains 0.01 to 2% by weight of at least one element selected from among Ar, Kr, Xe, and Ne. The device has the advantages of both organic and inorganic materials, a long lifetime, improved efficiency, low operating voltage, and low cost, and can provide a high luminance of light emission when applied to displays of the time-division driving mode, and realize large screen, high definition displays.

ed by  $(\text{Si}_{1-x}\text{Ge}_x)\text{O}_y$  wherein  $0 \leq x \leq 1$  and  $1.8 \leq y \leq 2.5$ , and further contains 0.01 to 2% by weight of at least one element selected from among Ar, Kr, Xe, and Ne. The device has the advantages of both organic and inorganic materials, a long lifetime, improved efficiency, low operating voltage, and low cost, and can provide a high luminance of light emission when applied to displays of the time-division driving mode, and realize large screen, high definition displays.

**FIG. 1**



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## EUROPEAN SEARCH REPORT

Application Number  
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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 668 620 A (AT & T CORP) 23 August 1995 (1995-08-23) * column 5, line 25-29: example 1 *	1,2	H01L51/20
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 02, 30 January 1998 (1998-01-30) -& JP 09 260062 A (TDK CORP), 3 October 1997 (1997-10-03) * abstract * -& US 5 981 092 A (MICHIO ARAI ET AL) 9 November 1999 (1999-11-09)	1,2	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H01L H05B
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
THE HAGUE		5 June 2000	De Laere, A
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ANNEX TO THE EUROPEAN SEARCH REPORT  
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